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(54) **LIGHTING DEVICE AND METHODS OF MAKING THE SAME**

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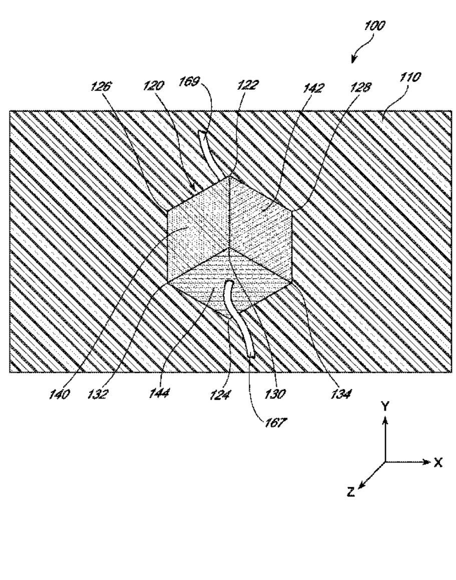
(57) **ABSTRACT**

Lighting devices are disclosed having a light-transmissive resin sheet and one or more light sources disposed within the light-emitting resin sheet. The light sources may, in some embodiments, be oriented so that a large portion of light emitted from the light sources exhibits total internal reflection within the light-transmissive resin sheet and is trapped inside the sheet. This total internal reflection may, for example, advantageously provide a more uniform light emitted from the lighting device when scattered from objects inside the sheet. Methods of making and using the lighting device are also disclosed.

25 Claims, 8 Drawing Sheets



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F21V 31/04	(2006.01)
F21V 33/00	(2006.01)
F21V 29/70	(2015.01)
F21W 121/00	(2006.01)
F21Y 101/02	(2006.01)
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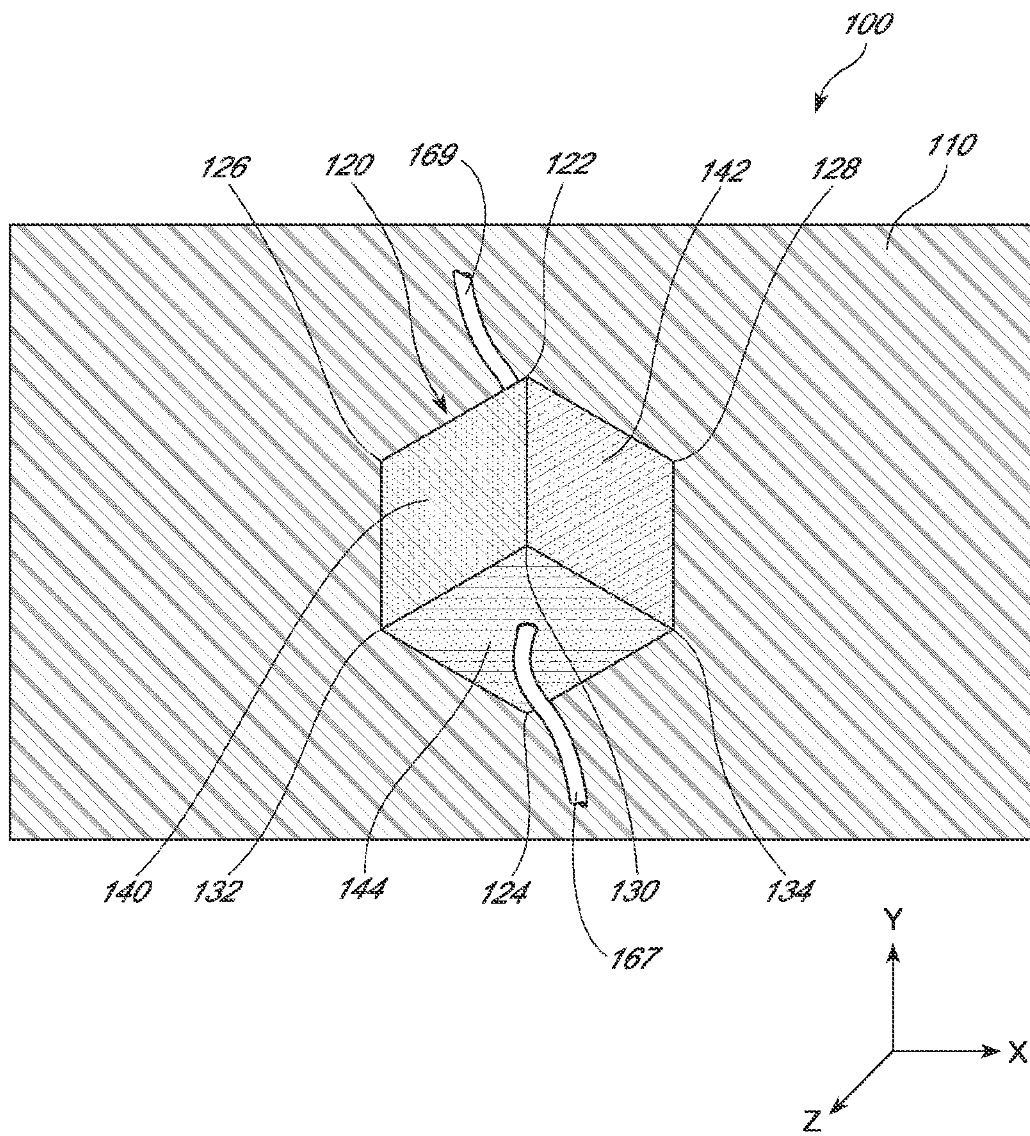

FIG. 1A

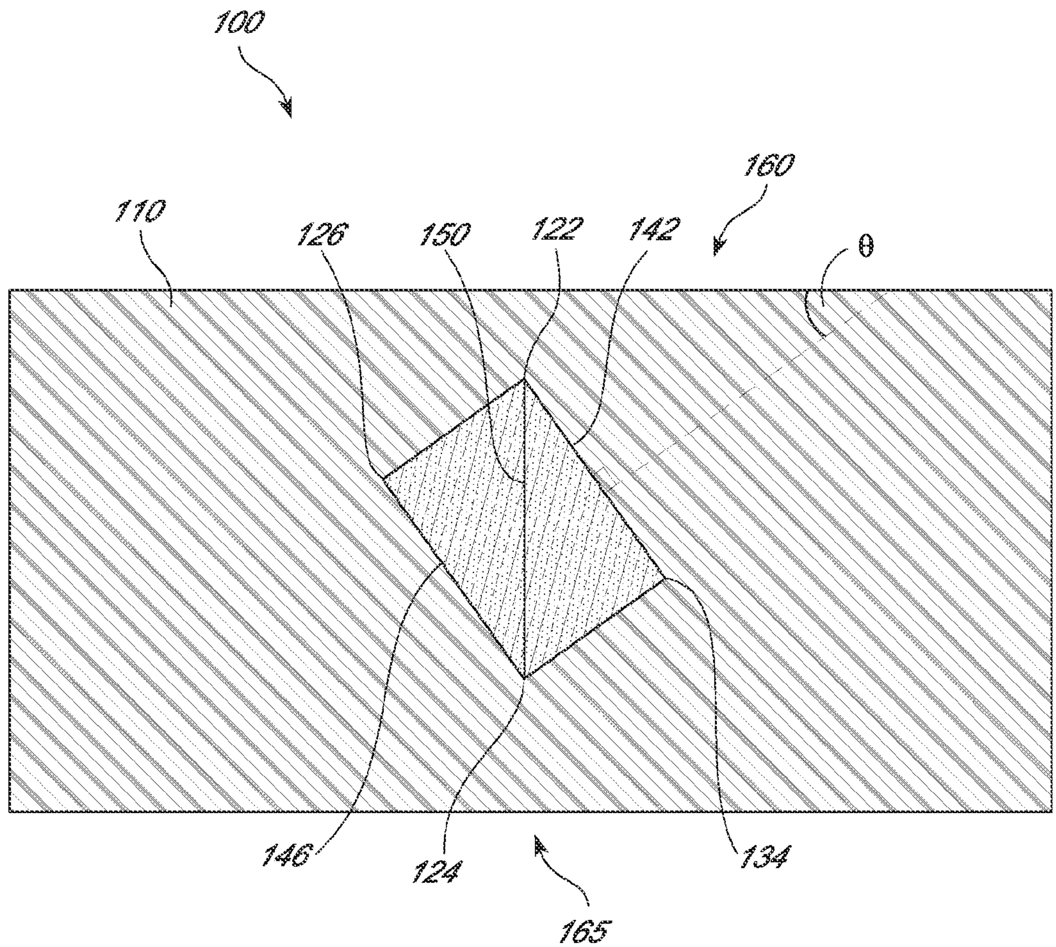

FIG. 1B

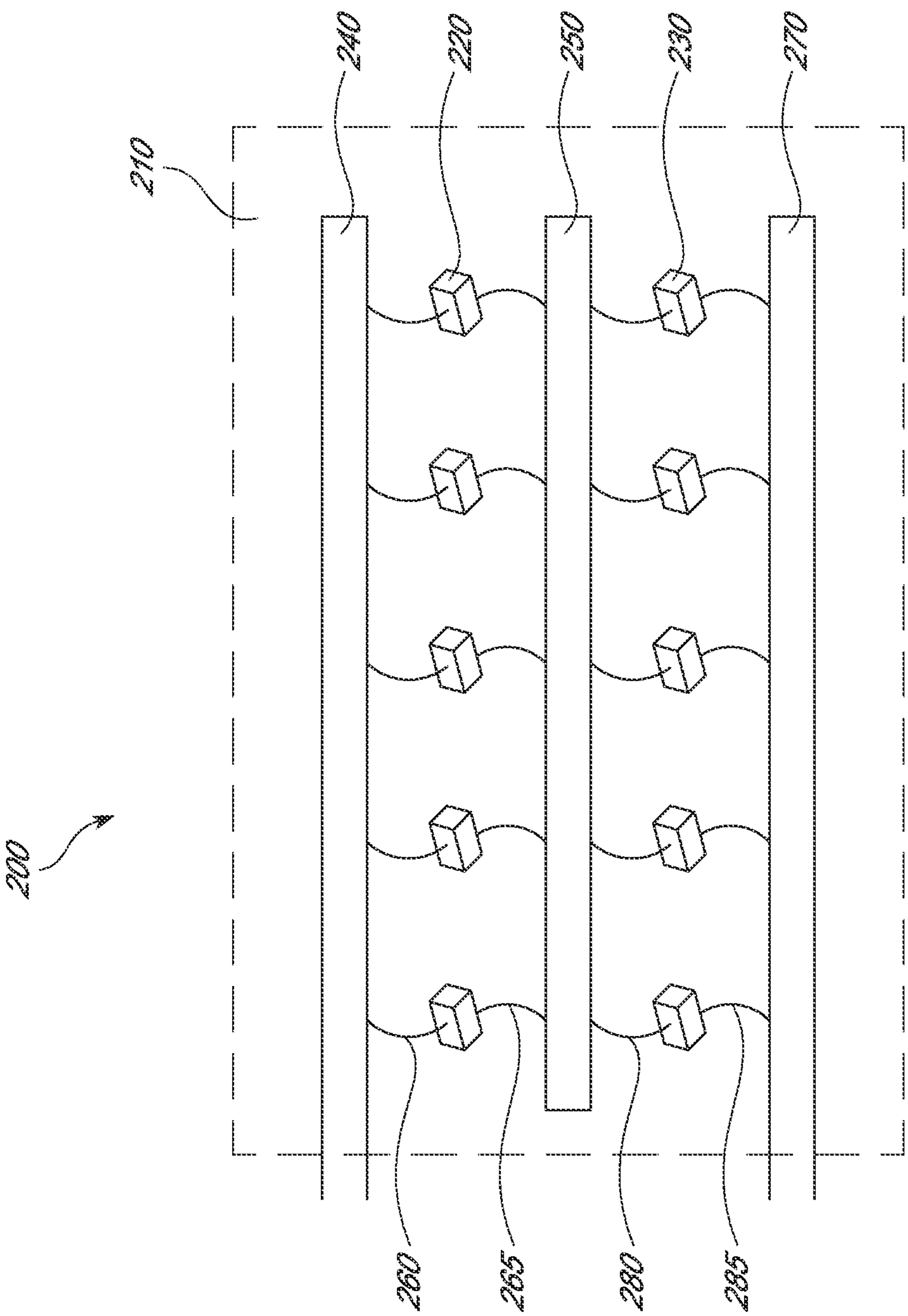

FIG. 2

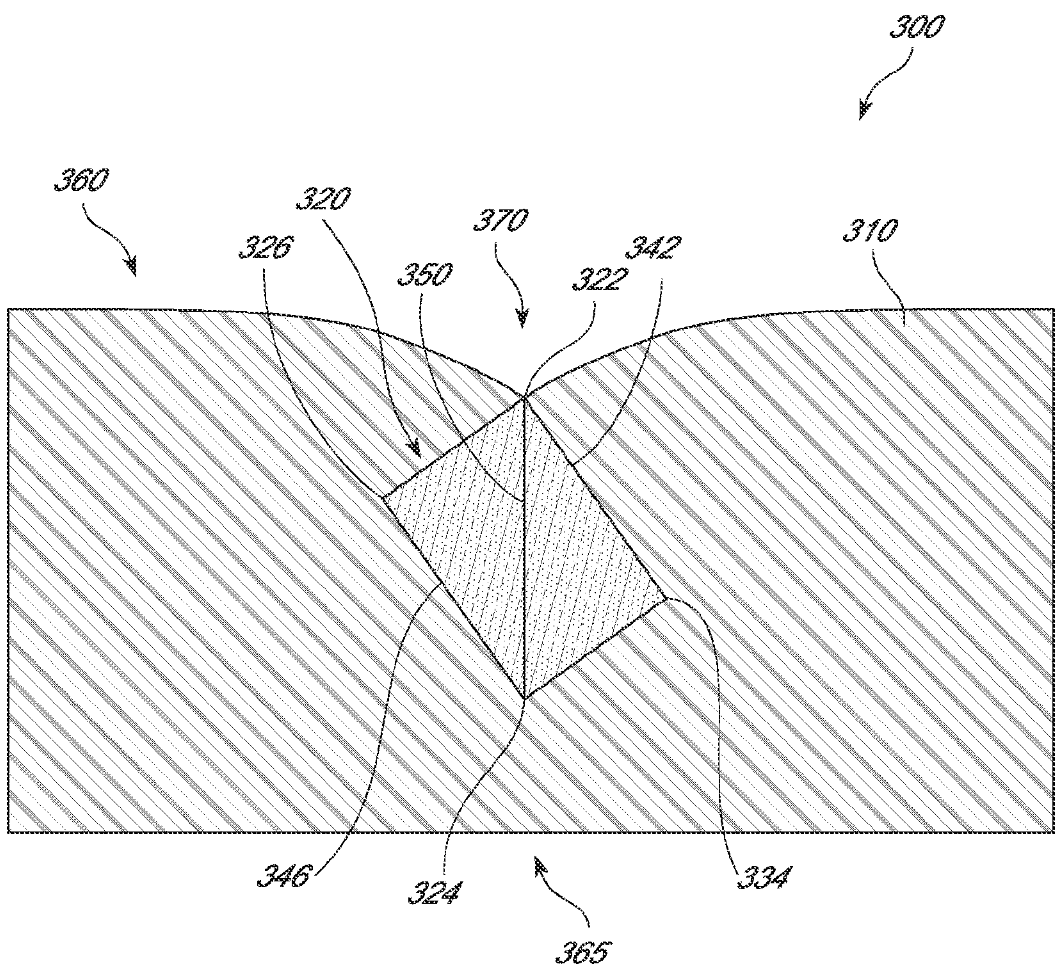

FIG. 3

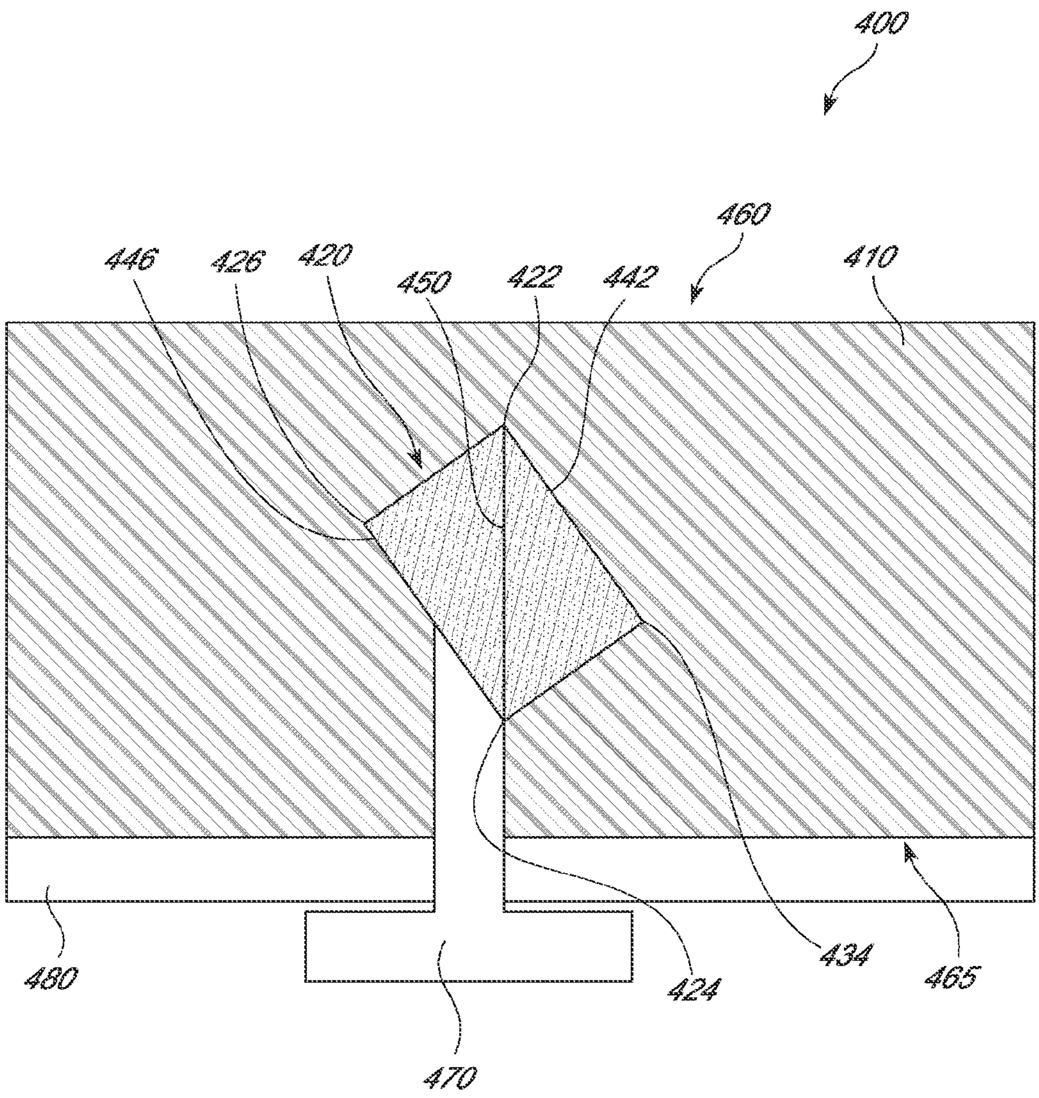

FIG. 4

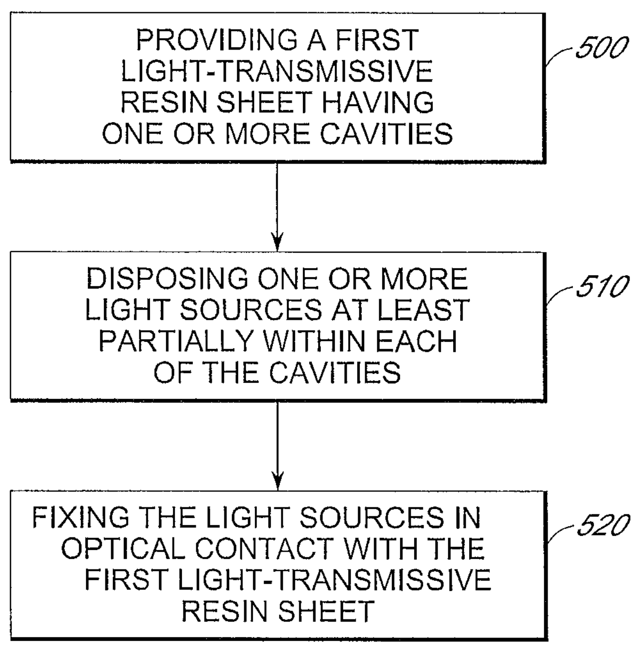
PROVIDING A FIRST LIGHT-TRANSMISSIVE RESIN SHEET HAVING ONE OR MORE CAVITIES
500
DISPOSING ONE OR MORE LIGHT SOURCES AT LEAST PARTIALLY WITHIN EACH OF THE CAVITIES
510
FIXING THE LIGHT SOURCES IN OPTICAL CONTACT WITH THE FIRST LIGHT-TRANSMISSIVE RESIN SHEET
520

FIG. 5

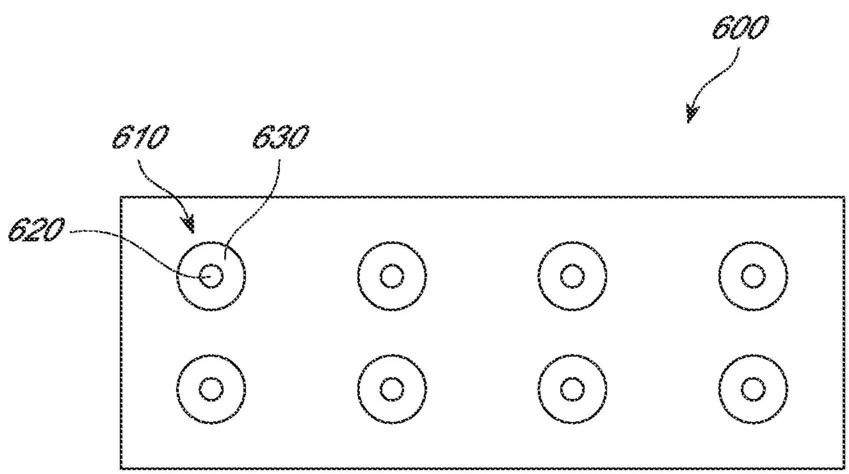

FIG. 6A

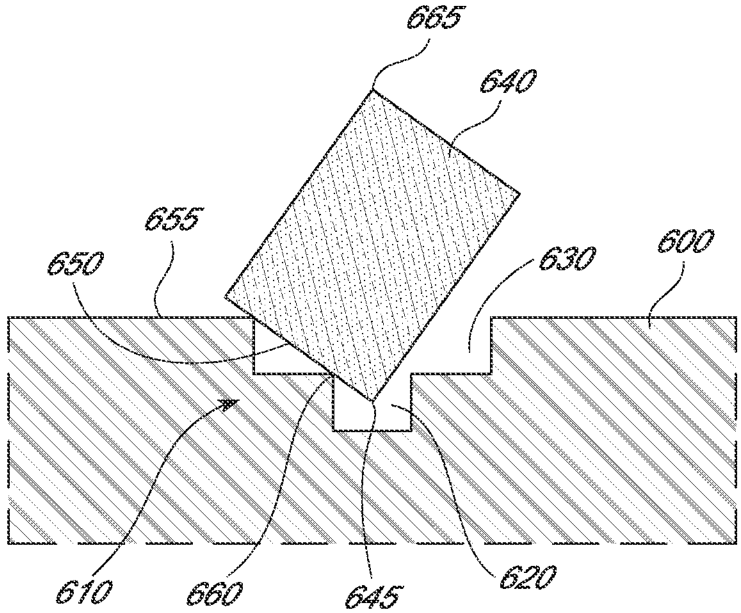

FIG. 6B

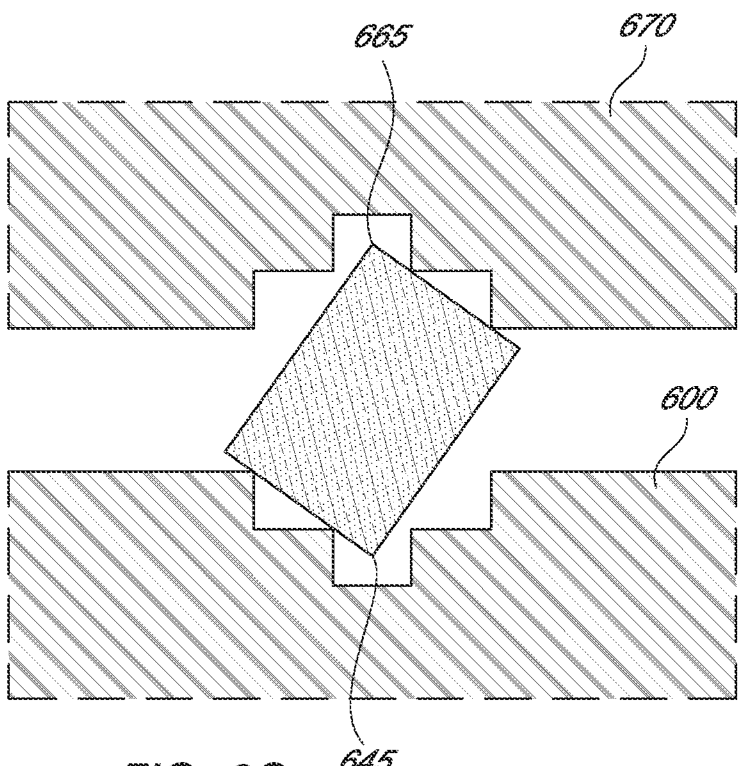

FIG. 6C

LIGHTING DEVICE AND METHODS OF MAKING THE SAME

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is the U.S. National Phase under 35 U.S.C. §371 of International Application No. PCT/US2012/057948, filed Sep. 28, 2012, the contents of which are herein incorporated by reference in its entirety.

BACKGROUND

Light emitting diodes (or LEDS) have been used in various lighting systems, such as lamps, flash lights, and display devices. Light emitting diodes are often selected for various lighting applications because they provide improved energy efficiency relative to other light sources, such as incandescent lights. In general, light emitting diodes emit a narrow beam of light that can lead to poor light distribution.

SUMMARY

Some embodiments disclosed herein include a lighting device. In some embodiments, the lighting device includes a light-transmitting resin sheet extending locally in a first plane; and one or more light sources disposed within the light-transmissive resin sheet, each of the light sources comprising one or more light-emitting faces each extending in different planes. In some embodiments, each of the different planes of the light-emitting faces form an angle with the first plane of the light-transmitting resin sheet of about 35° to about 75°.

Some embodiments disclosed herein include a light-transmissive resin sheet having a first surface and a second surface on opposite sides; and one or more polyhedral light sources disposed in the light-transmissive resin sheet between the first surface and the second surface. In some embodiments, in each of the polyhedral light sources: a first vertex is closest to the first surface of the light-transmissive resin sheet relative to other vertices on the same polyhedral light source; a second vertex is closest to the second surface of the light-transmissive resin sheet relative to other vertices on the same polyhedral light source; and a distance between the first vertex and the second vertex is about the same as a length of a largest dimension of the polyhedral light sources.

Some embodiments disclosed herein include a lighting device including a light-transmitting resin sheet extending locally in a first plane and one or more light sources disposed within the light-transmitting resin. In some embodiments, each of the light sources comprising two or more light-emitting faces extending in different planes that meet at a vertex. In some embodiments, each of the different planes of the light-emitting faces form about the same angle with the first plane of the light-transmitting resin sheet.

Some embodiments disclosed herein include a method for making a lighting device, the method including: providing a first light-transmitting resin sheet comprising one or more cavities on one side of the first light-transmitting resin sheet, wherein the first light-transmitting resin sheet extends in a first plane; disposing one or more light sources at least partially within each of the cavities of the first light-transmitting resin sheet, wherein the light sources each comprise one or more light-emitting faces extending in different planes, and wherein each of the different planes of the light-emitting faces form an angle with the first plane of the first light-transmitting resin sheet of about 35° to about 75°; and fixing the light sources in optical contact with the first light-transmitting resin sheet.

Some embodiments disclosed herein include a lighting device prepared according to any of method for preparing the lighting device disclosed in the present application.

Some embodiments disclosed herein include a method of producing light, the method including applying a voltage to one or more light sources effective for the light sources to emit light from one or more light-emitting faces on each of the light sources. In some embodiments, the light sources are disposed within a light-transmitting resin sheet extending in a first plane, and the light-emitting faces on each of the light sources extend in different planes that form an angle with the first plane of the light-transmitting resin sheet of about 35° to about 75°.

The foregoing summary is illustrative only and is not intended to be in any way limiting. In addition to the illustrative aspects, embodiments, and features described above, further aspects, embodiments, and features will become apparent by reference to the drawings and the following detailed description.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and other features of the present disclosure will become more fully apparent from the following description and appended claims, taken in conjunction with the accompanying drawings. Understanding that these drawings depict only several embodiments in accordance with the disclosure and are not to be considered limiting of its scope, the disclosure will be described with additional specificity and detail through use of the accompanying drawings.

FIG. **1**A is a partly perspective and partly cross-sectional view of one example of a lighting device within the scope of the present application.

FIG. **1**B is a cross-sectional view of a plane that includes vertex **122**, vertex **124**, vertex **134**, and vertex **126** of light source **120** in lighting device **100**.

FIG. **2** is a top view of one example of a lighting device having a plurality of light sources that are electrically coupled.

FIG. **3** is a cross-sectional view of a lighting device includes an indent disposed near a light source.

FIG. **4** is a cross-sectional view of one example of a lighting device having a heat-dissipation configuration that is within the scope of the present application.

FIG. **5** is a flow diagram showing one example of a process for making a lighting device.

FIG. **6**A shows a top view of one example of a light-transmissive resin sheet for use in the process for making the lighting device.

FIG. **6**B shows a partial, cross-sectional view of a cubic light source disposed in the cavity of the light-transmissive resin sheet.

FIG. **6**C shows a partial, cross-sectional view of a cubic light source disposed in a cavity between two light-transmissive resin sheets.

DETAILED DESCRIPTION

In the following detailed description, reference is made to the accompanying drawings, which form a part hereof. In the drawings, similar symbols typically identify similar components, unless context dictates otherwise. The illustrative embodiments described in the detailed description, drawings, and claims are not meant to be limiting. Other embodiments may be used, and other changes may be made, without departing from the spirit or scope of the subject matter presented here. It will be readily understood that the aspects of the present disclosure, as generally described herein, and illustrated in the Figures, can be arranged, substituted, combined, and designed in a wide variety of different configurations, all of which are explicitly contemplated and make part of this disclosure.

Some embodiments disclosed herein include a lighting device having a light-transmissive resin sheet and one or more light sources disposed within the light-emitting resin sheet. The light sources may, in some embodiments, be configured so that a large portion of light emitted from the light sources exhibits total internal reflection within the light-transmissive resin sheet. This total internal reflection may, for example, advantageously provide a more uniform light emitted from the lighting device. Methods of making and using the lighting device are also disclosed.

FIG. **1**A is a perspective view of one example of a lighting device within the scope of the present application. Lighting device **100** includes light-transmissive resin sheet **110** having light source **120** disposed within light-transmissive resin sheet **110**. Light source **120** is shown in perspective view and light-transmissive resin sheet **110** is shown in cross-sectional view, as if a portion of the light-transmissive resin sheet **110**, which typically surrounds the light source **120**, had been removed for the sake of illustration. Light source **120** can be, for example, an LED (light-emitting diode). Light source **120** is generally cubic-shaped with six planar faces. Face **140**, face **142**, and the three additional faces not visible in FIG. **1**A may each be configured to emit light. Face **144** can be electrically coupled to first electrode **167**. Second electrode **169** may be electrically coupled to a face on opposite sides of light source **120** relative to face **144** (e.g., a face that includes vertex **122**, vertex **126**, vertex **128** and a fourth vertex (not visible in FIG. **1**A)). By applying a voltage between the first and second electrodes, light source **120** may emit light from the light-emitting faces, such as face **140**, face **142**, and the three additional faces not visible in FIG. **1**A.

Light-transmissive resin sheet **110** is generally planar extending in the xz-plane. Light source **120** has a "cocked" orientation relative to light-transmissive resin sheet **110**, where an internal diagonal extending between vertex **122** and vertex **124** is generally parallel to the y-axis. Thus, the internal diagonal of light source **120** is normal to the plane of light-transmissive resin sheet **110** (e.g., normal to the xz-plane as depicted in FIG. **1**A). The center of light source **120** can be disposed at or near the midpoint along the thickness of light-transmissive resin sheet **110** (e.g., at the midpoint of light-transmissive resin sheet **110** along the y-axis as shown in FIG. **1**A).

FIG. **1**B is a cross-sectional view of a plane that includes vertex **122**, vertex **124**, and vertex **126** of light source **120** in lighting device **100**. In FIG. **1**B both the light-transmissive resin sheet **110** and the light source **120** are shown in cross section, on a single cross-sectional plane, which is the plane of the paper. Face **146**, visible in FIG. **1**B, is on the opposite side of light source **120** relative to face **142** and is not visible in FIG. **1**A. Internal diagonal **150** extends between vertex **122** and vertex **124**, lies in the plane of the paper, and is generally perpendicular to the plane of light-transmissive resin sheet **110**. The line indicating the face **142** appears longer than the lines perpendicular to it, because the line indicating the face **142** is a diagonal while the other line represents an edge, which in FIG. **1**B will be in ratio equal to root 2 assuming a cube shape (the cube being rotated by one-eighth of a turn about the axis **150** from the position shown in FIG. **1**A). Line **155** is perpendicular to face **142** and forms and an angle θ with the plane of light-emitting resin sheet. Similarly, face **142** extends in a plane that forms an angle $\psi=90-\theta$. Vertex **122** is disposed closest to first surface **160** of light-transmissive resin sheet **110** relative to the other seven vertices of light source **120**, including, for example, vertex **124**, vertex **126**, vertex **128**, vertex **130**, vertex **132** and vertex **134** shown in FIG. **1**A. Vertex **124** is disposed closest to second surface **165** of light-transmissive resin sheet **110** relative to the other seven vertices of light source **120**, including, for example, vertex **122**, vertex **126**, vertex **128**, vertex **130**, vertex **132** and vertex **134** shown in FIG. **1**A.

The light-transmissive resin sheet (e.g., light-transmissive resin sheet **110** depicted in FIG. **1**A) is not particularly limited so long as the light-transmissive resin sheet can transmit light emitted from the light sources. The light-transmissive resin sheet may have a light transmittance for light emitted by the light sources of, for example, at least about 50%; at least about 60%; at least about 70%; at least about 80%; at least about 90%; or at least about 95%. In some embodiments, the light-transmissive resin sheet is substantially transparent for light emitted from the light sources.

The light-transmissive resin sheet may, in some embodiments, be flexible. For example, the light-transmissive resin sheet may be flexible so that the lighting device can be spirally wound into a roll without damaging the light-transmissive resin sheet (e.g., without causing cracking or crazing). As another example, the light-transmissive resin sheet may have sufficient flexibility so that the light device may have curvature with a radius of about 10 cm or about 50 cm without damaging the light-transmissive resin sheet. In some embodiments, the light-transmissive resin sheet is rigid.

The light-transmissive resin sheet can include one or more resins. The light-transmissive resin sheet can include, for example, at least about 30% by weight of one or more resins; at least about 50% by weight of one or more resins; at least about 70% by weight of one or more resins; at least about 90% by weight of one or more resins; or at least about 95% by weight of one or more resins. The one or more resins may be a thermoplastic, a thermoset, or a mixture thereof. Non-limiting examples of resins that may be contained in the light-transmissive resin sheet include polycarbonates, acrylics, epoxies, polyolefins, polyesters, and copolymers thereof. In some embodiments, the one or more resins in the light-transmissive resin sheet are amorphous.

The dimensions of the light-transmissive resin sheet can be modified depending on various factors, such as the number and size of light sources in the lighting device. The light-transmissive resin sheet may have a thickness of, for example, at least about 0.1 mm; at least about 0.5 mm; at least about 1 mm; at least about 2 mm; at least about 5 mm; or at least about 1 cm. The light-transmissive resin sheet may have a thickness of, for example, less than or equal to about 5 cm; less than or equal to about 1 cm; less than or equal to about 5 mm; or less than or equal to about 3 mm. In some embodiments, the light-transmissive resin sheet has a thickness of about 0.1 mm to about 10 cm. The light-transmissive resin sheet may have a surface area (e.g., an area of first surface **160** of light-transmissive resin sheet **110** depicted in FIG. **1**B) of, for example, at least about 5 mm^2; at least about 50 mm^2; at least about 1 cm^2; at least about 5 cm^2; at least about 10 cm^2; or at least about 25 cm^2. Areas of many square meters are possible with the invention.

The lighting device may also include scattering elements disposed within the light-transmissive resin sheet. The scattering elements can generally be any change in materials or phase that exhibits a different indices of refraction relative the light-transmissive resin sheet, or reflective materials. The scattering elements can be, for example, titanium dioxide or silica particles or voids disposed in the light-transmissive resin sheet. In some embodiments, the scattering elements have a largest dimension of less than or equal to about 1 mm, or less than or equal to about 500 μm.

The lighting device can include one or more light sources (e.g., light source **120** as depicted in FIG. **1**A) disposed in the light-transmissive resin sheet. The light sources may be any known light source in the art. In some embodiments, light sources are light emitting diodes. The light source may include one or more light-emitting faces (e.g., one, two, three, four, five, six, seven, eight, nine, ten, or more light-emitting faces). The light source may, in some embodiments, have a polyhedral shape, such as a tetrahedron, a rhombohedron, a rectangle pyramid, a cube, a cuboid, a parallelepiped, a decahedron, a dodecahedron, and the like. In some embodiments, the light source is cuboidal. In some embodiments, the light source is cubic-shaped. In some embodiments, the light source is a cubic-shaped light emitting diode.

The light sources can have various orientations relative to the light-transmissive resin sheet. For example, the light sources may in the "cocked" orientation (e.g., the orientation of light source **120** as depicted in FIGS. **1**A and **1**B). The light sources may be oriented so that the light-emitting faces of each light source form an angle with a plane in which the light-transmissive resin sheet extends locally. For example, light-transmissive resin sheet **110** depicted in FIG. **1**A extends in the xy-plane and face **142** of light source **120** extends in a plane that forms an angle ψ with the xy-plane. As another example, the light-transmissive resin sheet may have a curved shape. The light-emitting faces of a light source disposed within the light-transmissive resin sheet can each extend in a plane that forms an angle with a plane that forms a tangent with the curved surface of the light-transmissive resin sheet at or near the location of the light source (if the light-transmissive resin sheet is curved rather than itself being planar). Thus, as used herein, the light-transmissive resin sheet "extending locally" in a plane refers to a plane that is tangent or parallel to the surface of the light-transmissive resin sheet at or near each light source.

The light sources may be oriented so that the light-emitting faces of each light source form an angle with a plane in which the light-transmissive resin sheet extends locally of, for example, at least about 35°; at least about 40°; at least about 45°; or at least about 50°. The light sources may be oriented so that the light-emitting faces of each light source form an angle with a plane in which the light-transmissive resin sheet extends locally of, for example, less than or equal to about 75°; less than or equal to about 70°; less than or equal to about 65°; or less than or equal to about 60°. In some embodiments, the light sources may be oriented so that the light-emitting faces of each light source form an angle with a plane in which the light-transmissive resin sheet extends locally of about 35° to about 75°. In some embodiments, the light sources may be oriented so that the light-emitting faces of each light source form about the same angle with a plane in which the light-transmissive resin sheet extends locally. For example, the light sources may be oriented so that the light-emitting faces of each light source form an angle of about 54.75° with a plane in which the light-transmissive resin sheet extends locally.

Without being bound to any particular theory, it is believed that orienting light-emitting faces of the light sources to form an angle of about 35° to about 75° with a plane in which the light-transmissive resin sheet extends locally can result in a large portion of emitted light to exhibit total internal reflection within the light-transmissive resin sheet. Scattering elements throughout the resin sheet can cause the light to be directed towards a surface of the light-transmissive resin sheet at an angle that is emitted from the lighting device rather than internally refracted. By internally refracting light when it is first emitted from the light sources, the lighting device may advantageously exhibit improved distribution of light.

The light-emitting faces in the light sources can be oriented so that lines extending perpendicular to the light-emitting faces (e.g., line **155** perpendicular to face **142** of light source **120** as depicted in FIG. **1**B) form an angle with a plane in which the light-transmissive resin sheet extends locally of, for example, at least about 15°; at least about 20°; at least about 25°; or at least about 30°. The light-emitting faces in the light sources can be oriented so that lines extending perpendicular to the light-emitting faces form an angle with a plane in which the light-transmissive resin sheet extends locally of, for example, less than or equal to about 55°; less than or equal to about 50°; less than or equal to about 45°; or less than or equal to about 40°. In some embodiments, the light-emitting faces in the light sources can be oriented so that lines extending perpendicular to the light-emitting faces form an angle of about 35.25° with a plane in which the light-transmissive resin sheet extends locally.

The internal diagonal of each of the light sources (e.g., internal diagonal **150** of light source **120** as depicted in FIG. **1**B) may, in some embodiments, form an angle with a plane in which the light-transmissive resin sheet extends locally of about 75° to about 90°, or about 80° to about 90°, or about 85° to about 90°. In some embodiments, the internal diagonal may form an angle of about 90° with a plane in which the light-transmissive resin sheet extends locally.

The light source may, in some embodiments, be oriented so that a first vertex of the light source is closest to a first surface in the light-transmissive resin sheet relative to other vertices in the light source. For example, as depicted in FIGS. **1**A & **1**B, vertex **122** in light source **120** is closest to first surface **160** of light-transmissive resin sheet relative to other vertices, such as vertex **126** and vertex **128**. The first vertex may be at least about 0.1 mm or at least about 0.5 mm closer to the first surface relative to the second nearest vertex on the same light source. The light source may, in some embodiments, be oriented so that a second vertex of the light source is closest to a second surface in the light-transmissive resin sheet relative to other vertices in the light source. For example, as depicted in FIGS. **1**A & **1**B, vertex **124** in light source **120** is closest to second surface **165** of light-transmissive resin sheet relative to other vertices, such as vertex **132** and vertex **134**. The second vertex may be at least about 0.1 mm or at least about 0.5 mm closer to the second surface relative to the second nearest vertex on the same light source. In some embodiments, the distance between the first surface and the first vertex is about the same as the distance between the second surface and the second vertex on the same light source. In some embodiments, each of the first of vertices on the light sources is about the same distance from the first surface of the light-transmissive resin sheet. In some embodiments, each of the second of vertices on the light sources is about the same distance from the second surface of the light-transmissive resin sheet.

The number of light sources disposed in the light-transmissive resin sheet is not particularly limited. The number of light sources disposed in the light-transmissive resin sheet can be, for example, at least about 1; at least about 2; at least about 8; at least about 16; at least about 32; at least about 64; at least about 128; or at least about 500. The number of light sources disposed in the light-transmissive resin sheet can be, for example, less than or equal to about 10,000; less than or equal to about 1000; less than or equal to about 500; less than or equal to about 128; less than or equal to about 64; or less than or equal to about 32. In some embodiments, the number of light sources disposed in the light-transmissive resin sheet is about 1 to about 10,000 or more; there is no limit to the number. The area density of the light sources is also not limited. In general, the greater the number of light sources per unit of area, the greater will be the number of lumens emitted by each unit area of the transmissive resin sheet.

The size of the light sources is not particularly limited. The light sources can have a largest dimension of, for example, at least about 0.1 mm; at least about 0.5 mm; at least about 1 mm; at least about 2 mm; at least about 5 mm; or at least about 1 cm. The light sources can have a largest dimension of, for example, less than or equal to about 10 cm; less than or equal to about 5 cm; less than or equal to about 1 cm; less than or equal to about 5 mm; or less than or equal to about 3 mm. In some embodiments, the light sources have a largest dimension of about 0.1 mm to about 10 cm. As an example, the light source can be a cubic-shaped light emitting diode having sides of about 1 mm and a largest dimension (or internal diagonal) of about 1.7 mm.

In some embodiments, the thickness of the light-transmissive resin sheet is greater than or equal to the largest dimension of the light sources. The thickness of the light-transmissive resin sheet (e.g., the distance between first surface **160** and second surface **165** in light-transmissive resin sheet **110** depicted in FIG. **1**B) relative to the largest dimension of the light sources (e.g., the length of internal diagonal **150** of light source **120** depicted in FIG. **1**B) can be, for example, at least about 1.5:1; at least about 2:1; or at least about 2.5:1. The thickness of the light-transmissive resin relative to the largest dimension of the light sources can be, for example, less than or equal to about 3:1; less than or equal to about 2.5:1; or less than or equal to about 2:1. In some embodiments, the thickness of the light-transmissive resin relative to the largest dimension of the light sources is about 1.5:1 to about 3:1.

The light sources may be randomly positioned in the light-transmissive resin sheet or may have a regular array (e.g., rectangular, square, hexagonal, rhombic, or oblique two-dimensional lattices). The light sources may be spaced apart a distance of, for example, at least about 0.1 mm; at least about 1 mm; at least about 5 mm; at least about 1 cm; at least about 2 cm; at least about 5 cm; or at least about 10 cm. The light sources may be spaced apart a distance of, for example, less than or equal to about 50 cm; less than or equal to about 25 cm; less than or equal to about 10 cm; less than or equal to about 5 cm; less than or equal to about 2 cm; or less than or equal to about 1 cm. In some embodiments, the light sources are spaced apart a distance of about 0.1 mm to about 50 CM.

In some embodiments, the light sources can have different orientations about an internal diagonal of the light sources. For example, the light sources may be randomly oriented about their internal diagonal relative to each other. As another example, the light sources may be oriented at fixed increments relative to each other (e.g., increments of 30°, 45°, 60°, 90°, 120°, etc.).

The lighting device can optionally include a reflective material to direct light to a desired region. For example, an aluminum coating may be applied to form the reflective layer. In some embodiments, a reflective material can be disposed on one or more edges (e.g., one, two, three, or four edges) of the light-transmissive resin sheet. The reflective material may prevent or reduce light emitted from the edges and increase light emitted from the top and/or bottom surfaces of the lighting device. In some embodiments, a reflective material can be disposed on one surface of the light-transmissive resin sheet. As an example, a reflective layer can be applied to first surface **160** of light-transmissive resin sheet **110** so that light is reflected and emitted from second surface **165** of light-transmissive resin sheet **110**. As such, the reflective material may increase light intensity in a desired direction.

FIG. **2** is a top view of one example of a lighting device having a plurality of light sources that are electrically coupled. Lighting device **200** includes light-transmissive resin sheet **210**, first row of light sources **220**, and second row of light sources **230**. Each of the light sources in first row of light sources **220** are electrically coupled in parallel to bus **240** and conductive band **250** via wires, such as wire **260** and wire **265**. Each of the light sources in second row of light sources **230** are electrically coupled in parallel to conductive band **250** and bus **270** via wires, such as wire **280** and wire **285**. When an appropriate voltage is applied between bus **240** and bus **270**, both first row of light sources **220** and second row of light sources **230** can emit light. Bus **240**, bus **270**, and conductive band **250** may each be disposed inside light-transmissive resin sheet or one side of light-transmissive resin sheet (e.g., disposed on first surface **160** of light-transmissive resin sheet **110** depicted in FIG. **1**B). Bus **240** and bus **270** may be electrically coupled to an electrical connector (e.g., a NEMA connector). The skilled artisan, guided by the teachings in the present application, will appreciate that numerous other configurations for powering the light sources may be used, and therefore the present application is not limited to the configuration depicted in FIG. **2**.

FIG. **3** is a cross-sectional view of a lighting device that includes an indent disposed near a light source. Lighting device **300** includes light-transmissive resin sheet **310** and light source **320**. Light source **320** has generally the same configuration as light source **120** depicted in FIGS. **1**A and **1**B. Consequently, vertex **322**, vertex **324**, vertex **326**, vertex **334**, face **342**, face **346**, internal diagonal **350**, first surface **360**, and second surface **365** in FIG. **3** correspond to vertex **122**, vertex **124**, vertex **126**, vertex **134**, face **142**, face **146**, internal diagonal **150**, first surface **160**, and second surface **165** in FIGS. **1**A and **1**B, respectively. First surface **360** of light-transmissive resin sheet **310** includes indent **370** laterally aligned with internal diagonal **350** of light source **320**. Without being bound to any particular theory, it is believed that the indent can increase an amount of light emitted from the light source that exhibits total internal reflection within the light-transmissive resin sheet, by changing the angle at which the most upwardly-directed rays leaving the light source **320** first encounter the resin/glass interface. In some embodiments, the light-transmissive resin sheet can include indents on both sides. For example, a second indent can be on second surface **365** that is laterally aligned with internal diagonal **350** (not shown).

The number of indents in the light-transmissive resin sheet may vary, for example, according to the number of light sources. The number of indents in the light transmissive resin sheet relative to a number of light sources in the light-transmissive resin sheet may be, for example, at least about 50%; at least about 80%; at least about 100%; or at least about 150%. The number of indents in the light transmissive resin sheet relative to a number of light sources in the light-transmissive resin sheet may be, for example, less than or equal to about 200%; less than or equal to about 150%; or less than or equal to about 100%. In some embodiments, the number of indents in the light transmissive resin sheet relative to a number of light sources in the light-transmissive resin sheet is of about 50% to about 200%. In some embodiments, the number of indents in the light transmissive resin sheet is about the same as the number of light sources in the light-transmissive resin sheet. As an example, a lighting device can include 16 light sources and 16 indents, each laterally aligned with a different light source on the same side of the light-transmissive resin sheet. In some embodiments, the number of indents in the light transmissive resin sheet is about twice the number of light sources in the light-transmissive resin sheet. As an example, a lighting device can include 16 light sources and 32 indents. 16 of the indents are on one side of the light-transmissive resin sheet and laterally aligned with a different light source. 16 of the indents are on an opposite side of the light-transmissive resin sheet and laterally aligned with a different light source.

FIG. **4** is a cross-sectional view of one example of a light device having a heat-dissipation configuration that is within the scope of the present application. Lighting device **400** includes light-transmissive resin sheet **410** and light source **420**. Light source **420** has generally the same configuration as light source **120** depicted in FIGS. **1**A and **1**B. Consequently, vertex **422**, vertex **424**, vertex **426**, vertex **434**, face **442**, face **446**, internal diagonal **450**, first surface **460**, and second surface **465** in FIG. **4** correspond to vertex **122**, vertex **124**, vertex **126**, vertex **134**, face **142**, face **146**, internal diagonal **150**, first surface **160**, and second surface **165** in FIGS. **1**A and **1**B, respectively. Heat sink **470** extends from second surface **465** of light-transmissive resin sheet **410** to face **446** of light source **420** to thermally couple light source **420** with the exterior of lighting device **400**. Reflective layer **480** is optionally disposed on second surface **465** so the light can be reflected to towards first surface **460**. Thus, lighting device **400** is configured to emit light from first surface **460**. A portion or all of the light sources in the lighting device can optionally be thermally coupled to a heat sink. For example, a lighting device having 10 light sources may also include 10 heat sinks, each thermally coupled to a different light source. Alternatively, one heat sink (for example, a metal plate or sheet) can be thermally coupled to various or plural light sources via respective heat sinks **470**. Reflective layer **480** may optionally act as such a single heat sink. The heat sinks **470** may also act as electrodes to make contact with respective light sources **420**, for example on a face hidden from view in FIG. **4**, with another electrode (not shown) to complete a circuit. In this case heat sink **470**, and optionally the reflective layer **480**, both conduct heat and electricity. Each heat sink **470** can be in close thermal contact with light source **420**.

The lighting device can be configured to obtain a desired level of light output by modifying, for example, the number of light sources. The lighting device may, for example, have a light output of, for example, at least about 100 lumens; at least about 500 lumens; at least about 1000 lumens; at least about 2000 lumens; or at least about 5000 lumens or more.

The lighting device can be configured to emit various colors, such as visible light, ultraviolet or infrared light, red, green, blue, yellow, or white light. In some embodiments, the lighting device emits white light. The light device may, in some embodiments, contain light sources that emit white light. In some embodiments, the lighting device includes light sources that emit different colors of light that, when combined, provide white light, or light sources which illuminate fluorescent materials or nanoparticles to cause them to emit light of certain or various colors. For example, the lighting device may contain different light sources that emit one of the colors red, green, or blue. The different light sources may together provide white light.

Some embodiments disclosed herein include a method for making a lighting device. The methods can be used, in some embodiments, to prepare any of the light devices disclosed in the present application. As an example, the methods can be used to prepare lighting device **200** depicted in FIG. **2**.

FIG. **5** is a flow diagram showing one example of a process for making a lighting device. The process includes "Providing a first light-transmissive resin sheet having one or more cavities," as illustrated in block **500**; "Disposing one or more light sources at least partially within each of the cavities," as illustrated in block **510**; and "Fixing the light sources in optical contact with the first light-transmissive resin sheet," as illustrated in block **520**.

At operation **500** depicted in FIG. **5**, a light-transmissive resin sheet is provided with cavities for receiving light sources. FIG. **6**A shows a top view of one example of a light-transmissive resin sheet for use in the process for making the lighting device. Light-transmissive resin sheet **600** includes a plurality of cavities **610**. Each cavity includes a cylindrical hole **620** and counterbore **630**. Cavities **610** can be dimensioned so that only one vertex of a light source can be inserted into cylindrical hole **620**. Cavities **610** may have the same or different dimensions. The light-transmissive resin sheet can have generally the same characteristics as those disclosed with regard to the light device. The cavities may be formed, for example, using standard drilling, imprinting, or molding procedures.

Returning to FIG. **5**, at operation **510** light sources can be disposed in the cavities of the light-transmissive resin sheet. In some embodiments, the light sources are disposed in the light-transmissive resin sheet so that the light sources have a desired orientation relative to the light-transmissive resin sheet. For example, the light sources may be disposed in the light transmissive resin sheet so that the internal diagonal of the light source may form an angle of about 90° with a plane in which the light-transmissive resin sheet extends locally. FIG. **6**B shows a partial, cross-sectional view of a cubic light source disposed in the cavity of the light-transmissive resin sheet. Light source **640** is disposed in cavity **610** so that vertex **645** is located within cylindrical hole **620**. Edge **650** contacts corner **655** and corner **660** formed by cylindrical hole **620** and counterbore **630**. Two additional edges of cubic light source **640** may also contact corner **655** and corner **660** formed by cylindrical hole **620** and counterbore **630** (not shown in the cross section; when viewed from above the sheet **600**, three edges spaced 120 degrees apart from one another can make contact simultaneously). Various other shapes for the cavity may be used, including but not limited to a cylindrical hole or countersink-shape. Another example is a cavity shape into which one apex of light source **640** will fit snugly, such that the light source **640** will be held in the correct orientation, for example with the line between two opposed vertices being substantially perpendicular to the surface of the resin sheet. This shape might be formed in the resin sheet by impressing a hot metal die into the surface of the resin sheet, and/or by first locally heating the area to be impressed by the die to form the impressed cavity shape.

A second light-transmissive resin sheet can optionally be disposed on an opposite side of the light sources. The second light-transmissive resin sheet may have the same configuration of cavities so that only one vertex from each light source can be disposed in different cavities from the second light-transmissive resin sheet. As an example, second light-transmissive resin sheet **670** can be placed over light source **640** as depicted in FIG. **6**C so that vertex **665** is disposed in cavity **680**. In some embodiments, scattering elements, such as silica particles can be disposed between the two light-transmissive resin sheets or fixed within one or both of the light-transmissive resin sheets.

In some embodiments, a heat sink may optionally be disposed in contact with the light source. For example, the light-transmissive resin sheet may include a cylindrical hole extending through the entire thickness of the light-transmissive resin sheet. An appropriate heat sink can be placed through the hole in thermal contact with the light source.

The light sources can be electrically coupled to an electrical connector before or after being disposed in the light-transmissive resin sheet. For example, the light sources can be electrically coupled to a bus as depicted in FIG. **2**. The can be completed using standard soldering procedures.

Referring again to FIG. **5**, at operation **530**, the light sources are fixed in optical contact with one or more light-transmissive resin sheets. Generally, the light sources may be fixed in optical contact by applying heat and optionally pressure. The heat can melt or soften the resin so that it becomes in optical contact with the light sources. Optical contact between the resin and the outside of the light sources may guide rays leaving the surface of the light source in such a way that they are internally reflected at the resin/air interface. In some embodiments, every portion of the surface of the light source from which rays pass into the resin is in optical contact with the resin. Here, "optical contact" means that the passage of rays between the light source and the resin is in accordance with the laws of optics as determined by their respective indices of refraction. In some embodiments, the heat may also weld together two light-transmissive resin sheets. The heat may be applied using, for example, friction, radiation (e.g., microwave, RF, infrared, and the like), or ultrasonic heating. After applying suitable heat and pressure, the light sources can be fixed within the light-transmissive resin (e.g., as light source **120** is fixed within light-transmissive resin sheet **110** as depicted in FIGS. **1**A & **1**B). The heat can be applied to one or both sides of the light source, and may be applied to both sides at different times. The heat can also be applied locally to reduce damage to the light sources. The skilled artisan, guided by the teachings of the present application, will appreciate that an indent (e.g., indent **370** of lighting device **300** depicted in FIG. **3**) can be formed by modifying processing characteristics, such as the heating time, heating temperature, and dimensions of the cavity. The skilled artisan will also be able to adjust the parameters of the process to optimize the shape of an indent, such as the indent **370** illustrated in FIG. **3**, which can result from the above-described processes. The shape of an indent **370** resulting from such processes might be adjusted by adjusting the particular shapes and dimensions of the cavities, and/or process parameters such as the local temperature of the resin, and the temperature as a function of time. The shape indent **370** itself can be optimized to internally reflect the highest proportion of the rays leaving the light source **120**.

The process for making the light device may be completed using continuous production. For example, an extended roll of a light-transmissive resin sheet can be continuously passed through stations for forming the cavities, disposing the light sources, electrically coupling the lights sources, and fixing the light sources.

Some embodiments disclosed herein include a method of producing light. The method can include applying a voltage to one or more light sources in a lighting device. The lighting device can be any of the lighting devices disclosed in the present application. As an example, the method can include applying a voltage between bus **240** and bus **270** in lighting device **200** as depicted in FIG. **2** to produce light.

With respect to the use of substantially any plural and/or singular terms herein, those having skill in the art can translate from the plural to the singular and/or from the singular to volume of wastewater can be received in the plural as is appropriate to the context and/or application. The various singular/plural permutations may be expressly set forth herein for sake of clarity.

It will be understood by those within the art that, in general, terms used herein, and especially in the appended claims (e.g., bodies of the appended claims) are generally intended as "open" terms (e.g., the term "including" should be interpreted as "including but not limited to," the term "having" should be interpreted as "having at least," the term "includes" should be interpreted as "includes but is not limited to," etc.). It will be further understood by those within the art that if a specific number of an introduced claim recitation is intended, such an intent will be explicitly recited in the claim, and in the absence of such recitation no such intent is present. For example, as an aid to understanding, the following appended claims may contain usage of the introductory phrases "at least one" and "one or more" to introduce claim recitations. However, the use of such phrases should not be construed to imply that the introduction of a claim recitation by the indefinite articles "a" or "an" limits any particular claim containing such introduced claim recitation to embodiments containing only one such recitation, even when the same claim includes the introductory phrases "one or more" or "at least one" and indefinite articles such as "a" or "an" (e.g., "a" and/or "an" should be interpreted to mean "at least one" or "one or more"); the same holds true for the use of definite articles used to introduce claim recitations. In addition, even if a specific number of an introduced claim recitation is explicitly recited, those skilled in the art will recognize that such recitation should be interpreted to mean at least the recited number (e.g., the bare recitation of "two recitations," without other modifiers, means at least two recitations, or two or more recitations). Furthermore, in those instances where a convention analogous to "at least one of A, B, and C, etc." is used, in general such a construction is intended in the sense one having skill in the art would understand the convention (e.g., "a system having at least one of A, B, and C" would include but not be limited to systems that have A alone, B alone, C alone, A and B together, A and C together, B and C together, and/or A, B, and C together, etc.). In those instances where a convention analogous to "at least one of A, B, or C, etc." is used, in general such a construction is intended in the sense one having skill in the art would understand the convention (e.g., "a system having at least one of A, B, or C" would include but not be limited to systems that have A alone, B alone, C alone, A and B together, A and C together, B and C together, and/or A, B, and C together, etc.). It will be further understood by those within the art that virtually any disjunctive word and/or phrase presenting two or more alternative terms, whether in the description, claims, or drawings, should be understood to contemplate the possibilities of including one of the terms, either of the terms, or both terms. For example, the phrase "A or B" will be understood to include the possibilities of "A" or "B" or "A and B."

In addition, where features or aspects of the disclosure are described in terms of Markush groups, those skilled in the art will recognize that the disclosure is also thereby described in terms of any individual member or subgroup of members of the Markush group.

As will be understood by one skilled in the art, for any and all purposes, such as in terms of providing a written description, all ranges disclosed herein also encompass any and all possible sub-ranges and combinations of sub-ranges thereof. Any listed range can be easily recognized as sufficiently describing and enabling the same range being broken down into at least equal halves, thirds, quarters, fifths, tenths, etc. As a non-limiting example, each range discussed herein can be readily broken down into a lower third, middle third and upper third, etc. As will also be understood by one skilled in the art all language such as “up to,” “at least,” “greater than,” “less than,” and the like include the number recited and refer to ranges which can be subsequently broken down into sub-ranges as discussed above. Finally, as will be understood by one skilled in the art, a range includes each individual member. Thus, for example, a group having 1-3 articles refers to groups having 1, 2, or 3 articles. Similarly, a group having 1-5 articles refers to groups having 1, 2, 3, 4, or 5 articles, and so forth.

While various aspects and embodiments have been disclosed herein, other aspects and embodiments will be apparent to those skilled in the art. The various aspects and embodiments disclosed herein are for purposes of illustration and are not intended to be limiting, with the true scope and spirit being indicated by the following claims.

One skilled in the art will appreciate that, for this and other processes and methods disclosed herein, the functions performed in the processes and methods may be implemented in differing order. Furthermore, the outlined steps and operations are only provided as examples, and some of the steps and operations may be optional, combined into fewer steps and operations, or expanded into additional steps and operations without detracting from the essence of the disclosed embodiments.

EXAMPLES

One skilled in the art will appreciate that, for this and other processes and methods disclosed herein, the functions performed in the processes and methods may be implemented in differing order. Furthermore, the outlined steps and operations are only provided as examples, and some of the steps and operations may be optional, combined into fewer steps and operations, or expanded into additional steps and operations without detracting from the essence of the disclosed embodiments.

Example 1

Preparing a Lighting Device

Two transparent polycarbonate sheets having a thickness of about 2 mm, length of about 15 cm, and height of about 15 cm are machined to produces cavities having about the same dimensions. A 4 by 4 grid of 16 cylindrical holes are drilled into the polycarbonate sheets, each of the holes are about 4 cm apart. The cylindrical holes have a depth of about 0.8 mm and a diameter of about 0.9 mm. Cubic light emitting diodes having a side of about 1 mm are pre-soldered to two short wires. The light emitting diodes are then disposed in each of the cavities of one of the polycarbonate sheets so that one vertex is inserted into each cavity. Buses are disposed adjacent to the light emitting diodes and aligned with the grid network of cavities. The two wires on each light emitting diode are soldered to different buses configured to have opposite polarity. The second polycarbonate sheet is placed over the light emitting diodes so that the cavities align with the light emitting diodes. The polycarbonate sheets are friction welded together at each of the light emitting diodes to form the lighting device. The lighting device is spirally wound into a roll for shipment.

Example 2

Lighting Device for Kitchen Lighting

Several lighting devices prepared according to Example 1 are each laminated to a reflective aluminum film on one side. The lighting devices are then fixed underneath kitchen cabinets using an adhesive so that the aluminum film is positioned between the light sources and the kitchen cabinets. The lighting devices are connected to a power supply and illuminate counters below the kitchen cabinets. It is expected that the light devices exhibit a uniform light distribution so that the location of individual light sources in the lighting device are not readily detectable.

Example 3

Maximal Angle of Rays for Light Sources

When an LED is oriented so that a line passing through its internal diagonal is perpendicular to the surface of the light-transmissive resin sheet in which it is embedded, then the edges radiating from the uppermost corner will be seen from above as three lines deployed at 120° to each other. Let the cube edges be one unit long. Since the three edges are all at 90° relative to one another, the right triangle formed by any two edges and a line through the center point of the side between those edges has sides in ratio 1:1:1.414. Now divide that triangle in half by a line lying in the cube side and bisecting the angle between the two edges, thus resulting in two congruent mirror-image right triangles. These two triangles will each have two sides measuring 1 and 0.707, so that by the Pythagorean theorem the third side will also measure 0.707.

Next, project the three edges onto the plane in which lie the three end points of the edges and also the center points of the cube's sides. By symmetry, the apex of the cube projects to the center point of an equilateral triangle having sides of length 1.414. The distance of the projected center point from any side can be obtained from a right triangle formed by one corner, the projected center point, and a midpoint of an edge, in which the base (from the end of the edge to the projected midpoint) measures 0.707, by the paragraph above, and the tangent of the included angle, 30 degrees, gives the length of the other leg as 0.707 tan 30=0.408.

Returning to 3-space, this 0.408 is also the base of a new, upright right triangle which lies inside the pyramid-like solid defined by the apex and the ends of the three cube edges. The hypotenuse of the triangle, extending from the apex to the midpoint of the cube's side, measures 0.707; its base measures 0.408, by the paragraph above. Thus the angle between the side of the cubical die and the line passing through two opposing corners of the cube is arcsine (0.408/0.707) or 35.25°. For a cubical LED die embedded in a planar sheet in the cocked position, a ray of light exiting the die face at a normal angle will make this angle with the resin/air interface, so the angle of incidence (which is the angle between the ray and a normal to the interface) is the complementary angle of 54.75°. This ray will be totally internally reflected, because the critical angle is arcsine (n_{air}/n_{resin}) or approximately arcsine 0.66=42°, and 54.75° exceeds it.

Example 4

Including Dimples

Light rays exiting from an LED into resin lie within a cone with an angle of 27° between the center line and the side, due to the index of refraction of LED semiconductor material being much higher than that of resin, which causes rays at larger angles to internally reflect within the LED. Therefore, some rays leaving the LED will hit the resin/air interface at 54.75°−27°=27.75°, which is less than the critical angle by about 14 degrees. Therefore some of the rays leaving the die will not be internally reflected but instead will be refracted at the interface and escape, causing bright spots around the LEDs at certain angles, and possibly making the illumination non-uniform.

The concave indent can increase the angle at which rays in the light cone from the die encounter the resin/air interface. If the upper edge of the light-ray cone hits not the planar interface but a portion which is tilted by 14° (according to the calculation in Example 3), then the rays at the upper edge of the cone will be internally reflected and so will all the others. Moreover, the internally-reflected rays will be turned toward the plane of the sheet by 28° and therefore will be trapped inside, as desired.

An LED die can be quite small, e.g., about a millimeter across or less, and in a typical LED package the die can barely be seen, in spite of the magnifying-lens effect of the rounded package tip. Therefore, the dimple can be quite small. If the upper corner of the die is close to the plane of the sheet, then its more-upwardly-inclined rays will intersect the plane of the sheet surface within a circle that is approximately as large as the LED itself. Also, the dimple need not be deep, because the surface tilt of only about 15° may ensure total internal reflection.

What is claimed is:

1. A lighting device comprising:

a light-transmitting resin sheet extending locally in a first plane; and

one or more light sources disposed within the light-transmissive resin sheet, each of the light sources comprising one or more light-emitting faces each extending in different planes,

wherein each of the different planes of the light-emitting faces form an angle with the first plane of the light-transmitting resin sheet of about 35° to about 75°.

2. The lighting device of claim **1**, wherein the light sources are light emitting diodes.

3. The lighting device of claim **1**, wherein the light sources have a cuboidal shape.

4. The lighting device of claim **3**, wherein each of the light sources comprises an internal diagonal extending between opposite vertices of the light sources, and wherein the internal diagonal of each of the light sources forms an angle of about 75° to about 90° with the first plane of the light-transmissive resin sheet.

5. The lighting device of claim **4**, wherein the internal diagonal of each of the light sources is approximately perpendicular to the first plane of the light-transmissive resin sheet.

6. The lighting device of claim **1**, wherein the light sources are cubic-shaped.

7. The lighting device of claim **1**, further comprising one or more electrical connectors electrically coupled to the light sources.

8. The lighting device of claim **7**, further comprising a bus configured to electrically couple the light sources and the electrical connectors.

9. The lighting device of claim **1**, further comprising a reflective material applied to one or more edges of the light-transmissive resin sheet.

10. The lighting device of claim **1**, further comprising an at least partially reflective material applied to at least one side of the light-transmissive resin sheet.

11. The lighting device of claim **1**, wherein the lighting device is rigid.

12. The lighting device of claim **1**, wherein the lighting device is flexible.

13. The lighting device of claim **1**, wherein a first number of the light sources are configured to emit a first color and a second number of the light sources are configured to emit a second color, and wherein the first color is different from the second color.

14. The lighting device of claim **1**, wherein the lighting device is configured to emit white light.

15. The lighting device of claim **1**, wherein the light-transmissive resin sheet comprises one or more indents on one side of the light-transmissive resin sheet, each of the indents are laterally aligned in the first plane with one of the light sources.

16. The lighting device of claim **1**, wherein the light sources form a regular array within the light-transmissive resin sheet.

17. The lighting device of claim **1**, wherein the light sources have different orientations about an internal diagonal of the light sources.

18. The lighting device of claim **1**, wherein the angle between each of the different planes of the light-emitting faces and the first plane of the light-transmissive resin sheet is about 50° to about 60°.

19. The lighting device of claim **1**, wherein the light-transmissive resin sheet comprises at least one of a polycarbonate, an acrylic, an epoxy, polyolefins, polyesters, and copolymers thereof.

20. The lighting device of claim **1**, further comprising one or more scattering elements disposed within the light-transmissive resin sheet.

21. The lighting device of claim **1**, further comprising one or more heat sinks disposed on one side of the light-transmissive resin sheet, wherein the one or more heat sinks are thermally coupled to the light sources.

22. The lighting device of claim **1**, wherein the light-transmissive resin sheet comprises one or more recesses on one side of the light-transmissive resin sheet, each of the recesses disposed near one of the light sources.

23. A lighting device comprising:

a light-transmitting resin sheet extending locally in a first plane; and

one or more light sources disposed within the light-transmitting resin, each of the light sources comprising two or more light-emitting faces extending in different planes that meet at a vertex, wherein each of the different planes of the light-emitting faces form about the same angle with the first plane of the light-transmitting resin sheet.

24. A method for making a lighting device, the method comprising:

providing a first light-transmitting resin sheet comprising one or more cavities on one side of the first light-transmitting resin sheet, wherein the first light-transmitting resin sheet extends in a first plane;

disposing one or more light sources at least partially within each of the cavities of the first light-transmitting resin sheet, wherein the light sources each comprise one or more light-emitting faces extending in different planes, and wherein each of the different planes of the light-emitting faces form an angle with the first plane of the first light-transmitting resin sheet of about 35° to about 75°; and

fixing the light sources in optical contact with the first light-transmitting resin sheet.

25. A method of producing light, the method comprising applying a voltage to one or more light sources effective for the light sources to emit light from one or more light-emitting faces on each of the light sources, wherein the light sources are disposed within a light-transmitting resin sheet extending in a first plane, and the light-emitting faces on each of the light sources extend in different planes that form an angle with the first plane of the light-transmitting resin sheet of about 35° to about 75°.

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